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Approved For Release 2009/07/09 : CIA-RDP87M00539R001001330001-0

Central Intelligence Agency

DDI-04998/85

Washington, D.C. 20505

08 OCT 1985

Dr. Matthew Meselson
Department of Biochemistry
and Molecular Biology
Harvard University
7 Divinity Avenue
Cambridge, MA 02138

Dear Dr. Meselson:

Thank you for the article describing your investigations of bee feces. While there is little doubt that some yellow spots collected in Southeast Asia and alleged to have come from chemical weapons attack sites are in fact bee feces, the identification of trichothecene toxins in other environmental samples and in blood and tissues of victims cannot be denied. Our results have been independently confirmed in multiple laboratories both domestically and abroad. Therefore, on the basis of all the information available to the Intelligence Community, we stand firm in our belief that trichothecene toxins have been used in Southeast Asia and Afghanistan.

Sincerely,

/S/ John N. McMahon

John N. McMahon
Deputy Director of Central Intelligence

DCI EXEC REG

C-125

SUBJECT: Letter to Dr. Meselson

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OSWR/STD/LSB/[redacted] (2 October 85) STAT

MEMORANDUM FOR: Director of Scientific and Weapons Research

FROM: Executive Assistant to the DDCI

STAT

[redacted]

Could you please have someone draft an acknowledgement to this from DDCI. Assuming we disagree with conclusions, we should say so.

Thanx,

[redacted]

Date 19 September 1985

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DEPARTMENT OF BIOCHEMISTRY AND MOLECULAR BIOLOGY
HARVARD UNIVERSITY

7 Divinity Avenue
Cambridge, Massachusetts 02138

Executive Registry
85- 3636

August 28, 1985

Mr. John McMahon, Deputy Director
[redacted] STAT
Central Intelligence Agency
[redacted] STAT

Dear Mr. McMahon,

For your possible interest, I enclose an article describing our studies of "Yellow Rain", the material which has been suspected of being a chemical warfare agent in Southeast Asia. The conclusion of this work is that "Yellow Rain" is a natural phenomenon, not a chemical warfare agent.

Sincerely yours,

Matthew Meselson

Matthew Meselson
Professor of Biochemistry
and Molecular Biology

Enclosure

MM:lal

I hope (and believe) this is progress — and that we can meet again.

DCI EXEC REG

C-125

an Article from SCIENTIFIC AMERICAN

SEPTEMBER, 1985 VOL. 253, NO. 3

unlikely to create new and anomalous ones. To the extent that verbal slips arise before items are chosen from the lexicon, the view is viable. The other view holds that a review process occurs well after items are selected from the lexicon but before articulation. In other words, an impending utterance is "edited" for linguistic integrity. This view too is viable, particularly to the extent that verbal slips arise after items are chosen from the lexicon.

Which view best explains how the system of speech production accomplishes its general avoidance of anomalous utterances? The question is not settled, but many proponents of one view or the other are moving toward middle positions. In any case, it is clear from the experimental work with slips of the tongue that the speech-production system concerns itself with more than whether a given utterance expresses the speaker's intended meaning. It somehow acts to ensure more generally that utterances are linguistically valid.

Another unsettled question is whether all natural verbal slips are the result of message-option conflicts. Our experimental work induces such conflict and yields abundant verbal slips, but it does not rule out the possibility of other types of slip. Indeed, a few natural slips are hard to explain in terms of message-option conflicts. It is difficult to imagine what conflicts could have led to slips such as "coregaty" (for "category"), "daygo plaints" (for "dayglo paints") and "checking cashes" (for "cashing checks"). Perhaps an explanation would emerge if one knew more about the context of each such slip; perhaps not. Obviously, however, the possibility that unrecognized sources of cognitive interference underlie some verbal slips is worth pursuing.

One thing that distinguishes human language from other forms of biological communication is that language virtually always offers a wide variety of alternatives for the expression of a message. The speaker need not deliberate over the choices; a choice can be made rather automatically and uttered flawlessly, all within an instant. Students of speech are far from understanding the process. To learn more one can take advantage of what appears to be a fairly general principle: Cognitive indecision over alternative forms for a message sometimes results in a slip of the tongue. By instilling cognitive indecision, eliciting verbal slips and examining the conditions that precede and facilitate the slips, we hope to learn more about the unique qualities of human speech.

Yellow Rain

A yellow substance found on rocks and leaves in Southeast Asia is alleged to be an agent of chemical war. The material is indistinguishable from the feces of indigenous honeybees

by Thomas D. Seeley, Joan W. Nowicke, Matthew Meselson, Jeanne Guillemin and Pongthep Akratanakul

Since the late 1970's reports of chemical warfare have emerged from Laos and Kampuchea. The allegations have come from refugees and soldiers opposed to the Laotian and Kampuchean governments that are supported by Vietnam, and they soon prompted investigations by the U.S. Government. In June, 1979, two officials of the Department of State conducted 22 interviews in Thailand with refugees from Laos, using a medical questionnaire prepared by U.S. Army experts in chemical warfare. The records of the interviews tell of bombs and rockets delivered by aircraft, which were said to have caused a variety of medical symptoms and many deaths.

The State Department investigators were given samples of the alleged chemical agent—pieces of vegetation spotted with a yellow substance—which were sent to the Army's Chemical Research and Development Center (CRDC) in Aberdeen, Md., for chemical analysis. Four months later Army physicians held further interviews with refugees who said they had witnessed chemical warfare in Laos, and they too received samples, which were subsequently transmitted to the CRDC. Again the samples were yellow spots a few millimeters in diameter, said to have been sprayed by an aircraft. In these early interviews and in subsequent interviews with refugees from Laos the deposits of the presumed chemical-warfare agent are almost always described as yellow; they have come to be known as yellow rain.

The diversity of the reported medical symptoms led the Army interviewers to conclude that several chemical agents had probably been employed: a nerve gas, a riot-control agent and a chemical that causes internal bleeding. Nevertheless, the Army's chemical analysis of pieces of vegetation with and without yellow spots, of yellow materials scraped from rocks and vegetation and of water—more than 50 samples in all—turned up nothing. No known chemical-warfare agent could be detected by even the most sensitive techniques.

On September 13, 1981, the scientific impasse seemed to be broken. Secretary of State Alexander M. Haig went before the Berlin Press Conference with a dramatic announcement: "For some time now, the international community has been alarmed by continuing reports that the Soviet Union and its allies have been using lethal chemical weapons in Laos, Kampuchea and Afghanistan. We now have physical evidence from Southeast Asia which has been analyzed and found to contain abnormally high levels of three potent mycotoxins—poisonous substances not indigenous to the region and which are highly toxic to man and animals."

The physical evidence to which Secretary Haig referred was a sample of vegetation from Kampuchea, reported to be contaminated with minute quantities of three fungal toxins called trichothecenes. The toxins were reported not by the Army but by a laboratory at the University of Minnesota to which the Government had sent the sample. Trichothecene toxins, which are produced by species of the fungal genus *Fusarium*, sometimes contaminate cereal grains, and in animals they are reported to cause skin lesions, vomiting, diarrhea and gastrointestinal bleeding. The detection of the toxins was the smoking gun the State Department relied on to charge the U.S.S.R. with waging or abetting chemical warfare.

Such actions would constitute violations of two international arms-control treaties: the 1925 Geneva Protocol, which bans the use but not the possession of chemical and biological weapons, and the 1972 Biological Weapons Convention, which bans even the possession of biological weapons, including toxin weapons. Although Laos and Kampuchea are not parties to the Geneva Protocol, the U.S., the U.S.S.R. and Vietnam have ratified the agreement. All the relevant countries, including Kampuchea, Laos, the U.S., the U.S.S.R. and Vietnam, are parties to the Biological Weapons Convention.

In this context the U.S. accusation is an extremely serious charge. The Government's evidence for the charge, however, is ambiguous. In particular, analyses by the Army have never detected trichothecene toxins—or any other chemical-warfare agents—in any samples from sites of alleged chemical attack in Kampuchea or in Laos, which puts the earlier reports of their presence in serious doubt. Moreover, our own investigations lead to an alternative explanation for yellow rain. We have good physical and biological evidence that yellow rain is the feces of Southeast Asian honeybees.

The evidence cited by the U.S. Government in support of its conclusions can be arranged in three main categories: the interviews with alleged witnesses of chemical warfare, the reports of trichothecene toxins in samples and the numerous descriptions and samples of the yellow material itself, collected from the alleged attack sites. A fourth category of evidence, secret intelligence reports, is not available for independent evaluation.

The accounts of chemical warfare come primarily from interviews with Hmong refugees from Laos. The Hmong are a highland people some of whom constituted a secret army maintained by the U.S. Central Intelligence Agency in Laos during the Vietnam war. Beginning with the collapse of U.S. support in 1975, many of the Hmong fled Laos for Thailand; thou-

sands of them have subsequently settled in the U.S., where they have been accepted as political refugees. Some of the Hmong who remained in Laos continued to resist the Laotian communist government and the occupying Vietnamese forces. Since 1978 Hmong refugees from Laos have reported numerous chemical attacks, which allegedly began in 1977 or before and continued at least until early last year.

Various investigators, including representatives of the State Department, the Army, the Canadian government and the United Nations as well as American volunteers, have conducted more than 200 interviews with alleged witnesses, most of whom were Hmong refugees who described suspected chemical attacks in Southeast Asia. Secretary of State George P. Shultz summarized the information collected between 1979 and mid-1982 in a report to Congress: "Usually the Hmong state that aircraft or helicopters spray a yellow rain-like material on their villages and crops." In an earlier report to Congress, Secretary Haig refers to a "reported symptomology of victims which commonly included skin irritation, dizziness, nausea, bloody vomiting and diarrhea and internal hemorrhaging." According to Secretary Haig's report, it was this constellation of symptoms that led in 1981 to the tests for trichothecenes toxins.

One of us (Guillemin) has examined the records of 217 such interviews, including 193 that were conducted with Hmong refugees, all done between January, 1979, and August, 1983. The descriptions of the color of the alleged chemical deposits remain consistent throughout the interviews, but the accounts of the nature of the alleged attacks and the medical symptoms following them vary widely.

More than 85 percent of the people interviewed who specify the color of the deposits of the alleged agent say it was yellow. As for the method of attack, about 40 percent of the respondents cite a specific type of aircraft: various propeller-driven airplanes, jets and helicopters are all mentioned. Only about a third of the respondents note any particular kind of system for disseminating the alleged chemical agent, and again the accounts vary: the reports cite rockets, bombs, sacks, air-

YELLOW SPOTS on vegetation in the forest of the Khao Yai National Park in Thailand closely match the samples and the descriptions of an alleged chemical-warfare agent known as yellow rain. According to reports published by the U.S. Department of State that summarize interviews with alleged witnesses to chemical warfare, yellow rain has been sprayed by aircraft, rockets and bombs in attacks against insurgents and civilians in Laos and Kampuchea, causing sickness and death. The authors present evidence that yellow rain has the same natural origin as the spots on the vegetation in the photograph have: they are the feces of Southeast Asian honeybees. The bees build as many as 100 nests in a tree and make massive cleansing flights that leave a swath of yellow, fecal spots.

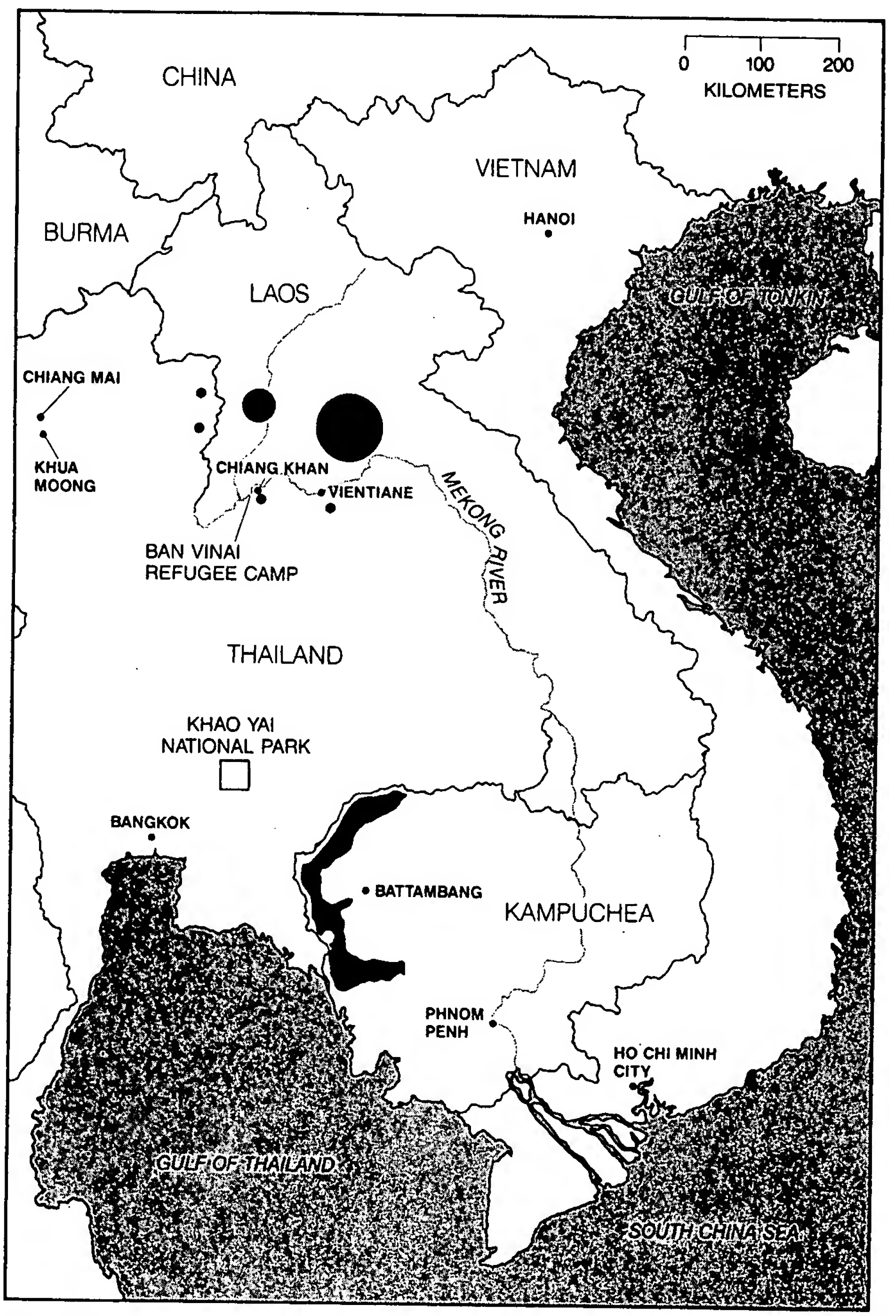
craft sprays and artillery fire. Notwithstanding the many samples of yellow rain that have come out of Laos and Kampuchea, no chemical munition or fragment has ever been obtained.

Sixty percent of the respondents report deaths. Nevertheless, the set of symptoms described as common in the Haig report is rarely seen. For example, only 8 percent of the respondents report having bloody vomiting, 10 percent report having bloody diarrhea and 21 percent report having rashes or blisters. If all the interviews are counted in which a symptom is cited, whether in the respondent or in others, the frequency of each symptom is still less than 25 percent. Only eight of the 217 people interviewed reported the three symptoms in combination, either in themselves or in other alleged victims. Remarkably, the frequency of reported illness is as high among respondents who describe arriving at a site after an attack as it is among respondents who were allegedly exposed directly.

One cannot dismiss the accounts of sickness and death, but one must be aware of the ambiguities in the interviews before interpreting them as evidence for chemical warfare. One main weakness in accepting the reports in the interviews at face value is the difficulty of distinguishing phenomena that are merely associated with one another by the respondents from phenomena that are causally interrelated. According to the interview reports, aircraft, yellow deposits, sickness and death were all observed on many occasions. Whether some of these phenomena caused the others, however, must be open to doubt. Indeed, as we shall discuss below, there is strong evidence that aircraft had nothing to do with the appearance of the yellow deposits and that the yellow material is not harmful to people.

There are other reasons to be skeptical about the interview reports. Almost all the interviews were done with refugees in camps who were selected in advance because they said they had been victims or witnesses of chemical attacks. Randomly chosen refugees from the same villages, who might have provided cross-checks, were not sought out. Both the respondents and their interpreters were aware that the purpose of the interviews was to gather information about chemical warfare, and no controls were employed to make sure they did not try to accommodate their responses to the categories and expectations of the Western investigators. Even the interviewers themselves were not free of unintentional bias. Their questioning often presumed the existence of chemical warfare, and they did not probe for alternative explanations. Solid conclusions about the occurrence of chemical warfare cannot be drawn from the evidence in the interviews.

There are several earlier cases in which sickness and death in Southeast Asia may have mistakenly been attributed to unusual materials from the sky. One example is reported in a 1972 study of the effects of herbicides in Vietnam, which was conducted for the Department of Defense by the National Academy of Sciences (NAS). According to this study, Vietnamese Montagnards interviewed in refugee camps attributed diarrhea, vomiting, skin rash, fever, dizziness, the coughing of blood and many deaths to the spraying of herbicides on or near their villages. Exposure to each of three different herbicides was reported to cause sickness and death, although none of these herbicides would be expected to have such severe effects. Moreover, a simultaneous study by the NAS showed that lowland Vietnamese exposed to the same herbicides rarely claimed such serious effects. It is likely that the reports of sickness and death among



REGIONS OF ALLEGED CHEMICAL ATTACKS are shown on the map in color. Most of the allegations have come from Hmong refugees in the Ban Vinai refugee camp in Thailand. In the forest of the Khao Yai National Park three of the authors (Akratanakul, Meselson and Seeley) found swaths of honeybee feces that closely resemble samples and descriptions of yellow rain. The three were caught in a fecal shower in the village of Khua Moong.

DATE OF ATTACK	DISSEMINATION SYSTEM	CHEMICAL AGENT	VOMITING	DIARRHEA	CHEST PAIN	RASHES OR BLISTERS	BLEEDING	DEATHS
OCTOBER 1977	ROCKET	YELLOW-GREY CHEMICAL	(+)					25
1978	BOMB	YELLOW CLOUD						SOME
FEBRUARY 1978	UNSPECIFIED	YELLOW RESIDUE			(+)	(+)	(+)	500
FEBRUARY 1978	BOMB	YELLOW RESIDUE					(+)	7
MARCH 1978	UNSPECIFIED	YELLOW DROPS			+			5
SPRING 1978	UNSPECIFIED	YELLOW SPLOTCHES	+	+	+	+	(+)	0–2
MAY 1978	4 BOMBS	YELLOW DUST						18
MID–1978	6 ROCKETS	RED GAS						SOME
JUNE 1978	ROCKET	YELLOW-RED RESIDUE	(+)		(+)	(+)		10–30
JUNE 1978	UNSPECIFIED	YELLOW GAS	(+)	(+)				90
OCTOBER 1978	8 ROCKETS	YELLOW-GREY FOG						ABOUT 150
OCTOBER 1978	4 ROCKETS	YELLOW CLOUD						8,000
OCTOBER 1978	ROCKET	RED GAS						0
NOVEMBER 1978	UNSPECIFIED	YELLOW AND BLUE GAS		+	+			80
NOVEMBER 1978	ROCKET	YELLOW GAS						29
NOVEMBER 1978	BOMB	YELLOW RAIN						2
1978 AND 1979	UNSPECIFIED	YELLOW RAIN	(+)					40
APRIL 1979	SACKS	RED-BROWN RESIDUE			+			4
APRIL 1979	UNSPECIFIED	YELLOW RAIN						20–30
APRIL 1979	UNSPECIFIED	YELLOW-BROWN RAIN	+	+	+	+		3
APRIL 1979	UNSPECIFIED	YELLOW SPOTS	(+)	(+)		(+)		2
MAY 1979	UNSPECIFIED	YELLOW RESIDUE	+	+	+	+		SOME

EARLY INTERVIEWS with Hmong refugees who said they had witnessed chemical warfare in Laos are summarized in the table. The interviews were done in June, 1979, by officials of the State Department. Symptoms reported by the refugees are designated by a plus sign; if the symptom was reported only in people other than the respondent, the plus sign is in parentheses. The summaries are arranged chronologically according to the date of the alleged attack. The interviewers were given samples of the alleged chemical agent from two of the attacks, namely the fourth and the last entries in the table. These samples were yellow spots on pieces of vegetation.

Montagnard refugees can be traced in part to endemic diseases and in part to hearsay and exaggeration. Medical symptoms and deaths attributed to yellow rain may have a similar genesis.

In principle, chemical analysis of samples collected from the sites of alleged attacks could lead to firm conclusions about the occurrence of chemical warfare. In support of its conclusions the State Department has often cited reports of trichothecenes in environmental and biomedical samples. The U.S. Army and two university laboratories have tested a combined total of about 100 environmental samples from alleged attack sites in Laos and Kampuchea for trichothecenes. Trace amounts of trichothecenes have been reported in six of these samples, all collected in 1981 and 1982. Furthermore, the trichothecene *T*-2 or its metabolite *HT*-2 have been reported in the blood, urine or tissues of 20 people, all said to have been exposed to chemical attack in 1981, 1982 or 1983. The Army has not examined any of the biomedical samples, and so it can provide no confirmation for the positive test reports. There is a serious conflict, however, between the Army's results for the environmental samples and the ones cited by State.

All the positive reports for trichothecenes have come from the two university laboratories. Chester J. Mirocha of the University of Minnesota tested six environmental samples from alleged attack sites, sent to him from the CRDC by way of the Armed Services Medical Intelligence Center at Fort Detrick, Md. Mirocha reported that five of the six samples were positive for trichothecenes; they include a sample of vegetation, a water sample and three samples of material scraped from rocks and vegetation. Mirocha's analyses were the earliest ones done for trichothecenes, and they included the analysis on which Secretary Haig based his charge. Joseph D. Rosen of Rutgers University analyzed one sample, a yellow material obtained by the television-news organization of the American Broadcasting Company (ABC Television News), and he reported that the sample was positive.

On the other hand, since late in 1982 more than 80 environmental samples from alleged attack sites in Laos and Kampuchea have been analyzed for trichothecenes by the Army laboratory, and not one of them has been found to contain the toxins. There is little doubt about the Army's ability to detect trichothecenes: control samples intentionally contaminated with trichothecenes have consistently yielded positive test results. Moreover, like the six environmental samples reported as being positive for trichothecenes by the university laboratories, most of the samples analyzed by the Army were vegetation, water or yellow materials scraped from rocks and leaves. About 50 of the Army's samples were collected in 1981 and the rest later.

One of the environmental samples that Mirocha reported as being positive has also been tested by the CRDC. The sample is a yellow material scraped from rocks in Laos in 1981, and according to Mirocha's results, it carried the highest concentration of a trichothecene toxin reported for any of the samples: 143 parts per million of the toxin *T*-2. About a year after Mirocha's analysis the CRDC tested part of the same yellow material from which Mirocha's sample had been taken. The Army found no trace of *T*-2.

Such gross divergence in the test results for trichothecenes—six out of seven positive, 80 out of 80 negative—cannot plausibly be explained by statistical errors in sampling. Instead it raises a number of serious and still unanswered questions: How long would the toxins be stable and detectable in the relevant samples? Could the positive test results somehow be caused by experimental artifacts? Can one be assured of the authenticity and the integrity of the samples? Without answers to these questions the analyses of the samples cannot be accepted as evidence that chemical warfare was waged with trichothecene toxins.

The third category of evidence cited in support of the chemical-warfare theory consists of the frequent descriptions and many samples of the yellow

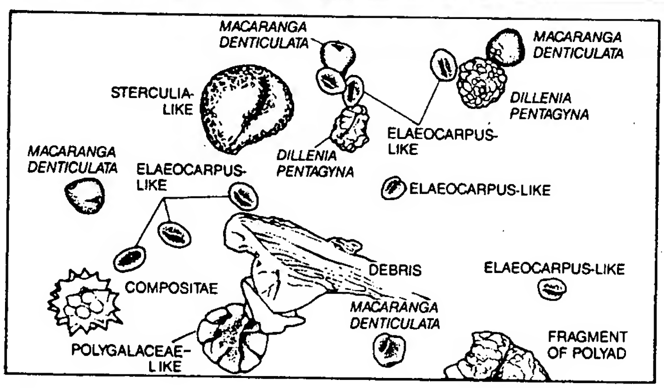
substance said by the refugees and presumed by the Government to be a chemical-warfare agent. According to various Government reports, including the reports to Congress by secretaries Haig and Shultz, the substance is a "yellow rain-like material" that falls to form "sticky yellow spots" that soon dry to a powder. Since 1979 dozens of samples have been given to American, British, Canadian and other officials.

In January, 1982, investigators at the British Chemical Defense Establishment in Salisbury, England, found that samples of yellow rain contain large amounts of pollen. Soon afterward the same discovery was made independently by workers at Mahidol University in Bangkok and at Agriculture Canada in Ottawa. The findings have been confirmed for samples from at least 30 alleged attacks in Laos and Kampuchea, including samples given to the U.S. investigators in 1979. According to Emory W. Sarver of the CRDC, "most of the samples that are of yellow rain are fairly dry and they have a high level of pollen grains in them." To the best of our knowledge all the samples of the yellow material examined under the microscope have, without exception, been found to consist primarily of pollen.

The reasons for adding pollen to a chemical-warfare agent are obscure, and they have not been adequately explained by the proponents of the chemical-warfare theory. In a briefing held in November, 1982, and distributed by the U.S. Information Agency, Gary Crocker of the State Department notes that the particles of pollen are not windborne but rather are "the type of thing a honeybee would take from flowers." The physical introduction of pollen into the alleged chemical agent would then presumably require that pollen gathered by honeybees be harvested, mixed with fungal toxins and dispersed from weapons. Neither the logistics of the enormous harvesting operation required to account for the quantities of pollen that would be needed nor the significance of the kinds of pollen found in the samples is addressed by that hypothesis. We shall have more to say on this point.

In the same 1982 briefing Sharon A. Watson of the U.S. Armed Forces Medical Intelligence Center suggested a role for the pollen in the chemical agent: "The agent, as it comes down, is wet, and at this time the primary exposure appears to be through the skin.... But as the agent dries, a secondary aerosol effect can be caused by kicking up this pollen-like dust that is of a particle size that will be retained in the bronchi of the lung." Watson's explanation is faulty on two counts. First, a relatively large amount of energy is needed to form an aerosol from a congealed deposit. Second, the samples of yellow rain examined in the laboratory show no tendency to disperse.

The abundance of pollen and the lack of a plausible military explana-



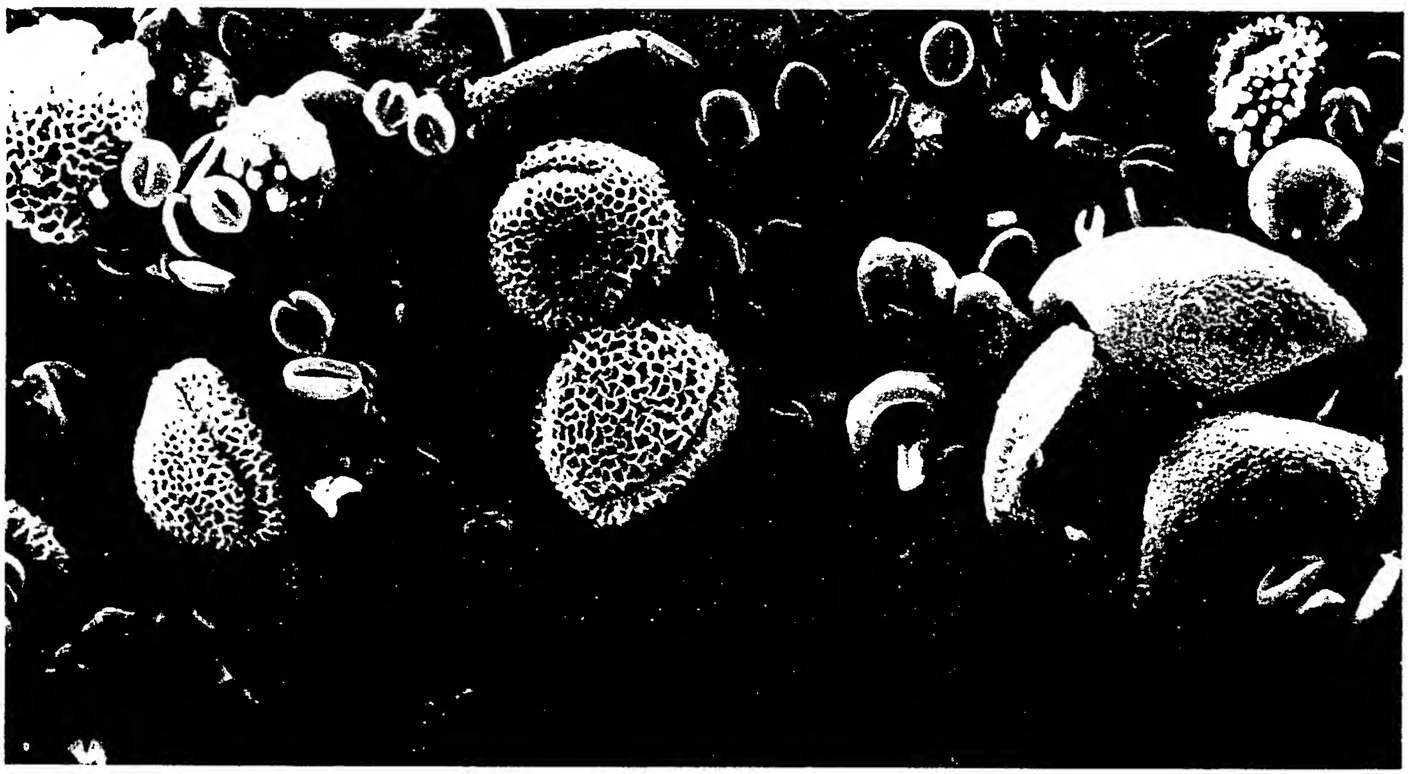
POLLEN GRAINS make up the bulk of the material both in yellow rain deposits and in honeybee feces. The scanning electron micrograph on this page shows pollen in the sample of yellow rain from Laos, obtained by ABC Television News; the scanning electron micrograph on the opposite page shows pollen from the feces of the honeybee *Apis dorsata*. Identifications and classifications of the pollen are given in the key maps. There are three types of pollen

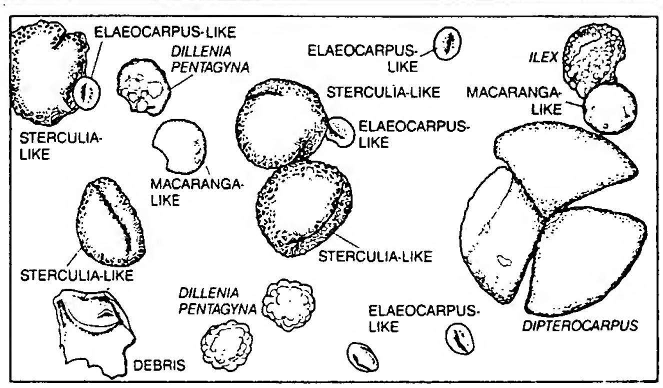
tion for its presence suggested that yellow rain has a natural origin and led us to obtain samples of yellow rain for independent examination. The samples, which were made available to us by the Canadian government, include leaves and pebbles, each spotted with one or more yellow deposits. They were given to Canadian diplomatic personnel in Thailand by Hmong refugees, who said they had gathered the samples in late March or early April, 1982, at the sites of two chemical attacks in Laos. We have also examined a sample of yellow material obtained by ABC News and said to have been scraped from vegetation by Hmong soldiers at a site of an alleged chemical attack in Laos in March, 1981. The ABC News sample is the same one that was analyzed by Rosen, who reported it to contain 48 parts per million of *T*-2, in addition to other trichothecenes.

In April, 1983, Carl Kaysen of the Massachusetts Institute of Technology, Stewart Schwartzstein of the Institute for Foreign Policy Analysis and one of us (Meselson) assembled a conference in Cambridge, Mass., to discuss the evidence for chemical warfare in Southeast Asia, with particular emphasis on the source and composition of yellow rain. The conference participants included experts in anthropology, botany, chemical warfare, chemistry, medicine and mycology as well as officials from the U.S. Army and the State Department. Peter M. S. Ashton of Harvard University made a crucial observation at the meeting. Preliminary analysis published by the Australian Department of Defense in Canberra showed that the plant families represented in the yellow rain pollen could be identified with certain families strongly represented in Southeast Asia. Ashton pointed out that the flowers of these plant families are frequently visited by bees.

If yellow rain has a natural origin, Ashton's observation raised an important question: How could the pollen come to be highly concentrated in rain-like spots on rocks and leaves? The puzzle led Ashton to approach one of us (Seeley), who is an expert on the behavior and ecology of honeybees. Seeley noted that the Government's description of yellow rain is an accurate description of the fecal droppings of honeybees. Like yellow rain, the feces take the form of small, yellow, pollen-filled spots that dry to a powder.

To test the hypothesis that yellow rain is the feces of Asian honeybees we began a series of comparisons between yellow rain and bee feces. Fred Dyer, then a graduate student at Princeton University, was in India at the time studying Asian honeybees. Dyer sent us fecal deposits of *Apis cerana* and *Apis dorsata*, two of the three Asian species of honeybees. Yellow rain is of course most often described as yellow, but according to witnesses, its color also varies from pale yellow through shades of yellowish brown





visible in the electron micrograph of yellow rain that match grains seen in the micrograph of bee feces: the Elaeocarpus-like grains, which are the smallest grains and the most numerous; the Sterculia-like grains, which have a reticulate surface, and the grains of *Dillenia pentagyna*, which have a clumpy, irregular surface. The scanning electron micrographs were made by one of the authors (Nowicke); the magnification of each micrograph is 950 diameters.

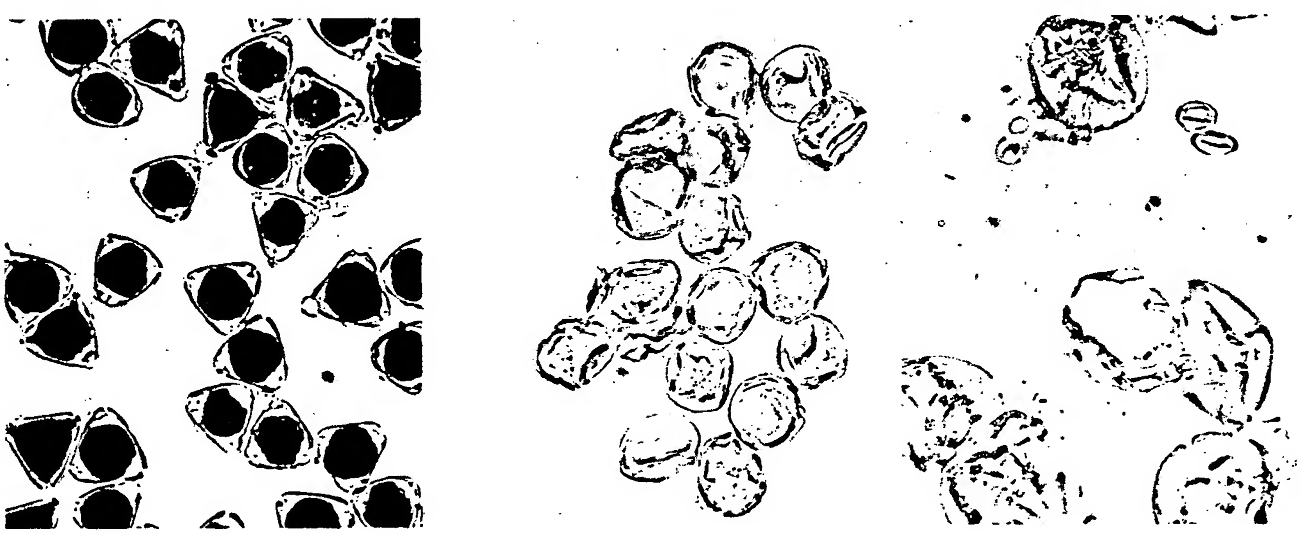
POLLEN TYPE	SAMPLES OF YELLOW RAIN								FECES OF HONEYBEE *APIS DORSATA*		HONEY FROM CHIANG KHAN, THAILAND
	ABC NEWS	LEAF 3, SPOT A	LEAF 3, SPOT B	LEAF 4, SPOT A	LEAF 4, SPOT B	LEAF 5, SPOT A	LEAF 5, SPOT B	ROCK	CHIANG MAI, THAILAND	KHAO YAI NATIONAL PARK	
AQUIFOLIACEAE *ILEX*		⊙		○	○	○	○		○	○	
COMPOSITAE	○								○		
DILLENIACEAE											
DILLENIA HOOKERI	○									○	○
DILLENIA PENTAGYNA	○									○	○
DIPTEROCARPACEAE *DIPTEROCARPUS*										○	
ELAEOCARPACEAE ELAEOCARPUS-LIKE	⊙									⊙	⊙
EUPHORBIACEAE											
MACARANGA DENTICULATA	⊙	⊙		●	⊙	⊙	⊙				
MACARANGA-LIKE										⊙	
FAGACEAE-LIKE			●					⊙	○		○
GRAMINEAE									●		
ICACINACEAE *APODYTES*	○	⊙		○	●	⊙	○				
MELASTOMATACEAE	○	⊙		⊙	⊙	○	⊙				○
STERCULIACEAE STERCULIA-LIKE	○									⊙	

○ MINOR COMPONENT, LESS THAN 5 PERCENT OF POLLEN GRAINS IN SAMPLE

⊙ 5–50 PERCENT OF POLLEN GRAINS IN SAMPLE

● MORE THAN 50 PERCENT OF POLLEN GRAINS IN SAMPLE

POLLEN TYPES in samples of yellow rain from Laos and in samples of honey and honeybee feces from Thailand are listed in the table. Pollen types not identified in the samples are not included in the table. The ABC News sample of yellow rain is one of six environmental samples reported to contain trichothecenes, which are toxic substances produced by certain fungi. It was collected by a Hmong soldier at the site of an alleged chemical attack in 1981. The leaf and rock samples were collected by a group of Hmong at two sites of alleged attack in 1982. The six leaf samples represent two spots on each of three leaves. Spot *B* on leaf 3 is made up almost entirely of Fagaceae-like pollen, a type that is absent from spot *A* on the same leaf. The remaining leaf spots include similar pollen types but in quite different proportions. Such diversity of pollen from spot to spot would not be expected from a manmade spray. The rock sample was obtained from rocks with yellow spots. The samples of bee feces were made by pooling several spots scraped from leaves by the authors. All the pollen types identified in yellow rain are from plant families common in Southeast Asia. The table shows these types are also present in honey and in the feces of *Apis dorsata,* which demonstrates that the pollen types in yellow rain are gathered by indigenous honeybees.



PRESENCE OF PROTEIN in pollen grains is indicated by the dye Coomassie Brilliant Blue. Protein is digested out of the grains by enzymes in the intestinal tract of the bee, and so pollen grains that have passed through a bee do not stain in the presence of the dye. The pollen grains in the photomicrograph at the left were gathered and stored (but not eaten) by the honeybee *A. dorsata;* they stain a deep blue. In the photomicrograph in the middle are pollen grains from the feces of *A. dorsata* that were also treated with the dye; they do not stain. In the photomicrograph at the right are pollen grains in the ABC News sample of yellow rain. None of the grains in the right photomicrograph are stained by the dye, just as one would expect if the yellow rain sample is made up of bee feces. The photomicrographs were made by Phillip M. Rury of Harvard University; the magnification in all three photomicrographs is 520 diameters.

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and reddish brown. Our own samples of yellow rain confirm this distribution of colors, and the distribution matches that of the Asian honeybee feces we received from India.

As we noted above, the average diameter of the spots of yellow rain that are reported to fall on alleged attack sites is about three millimeters, and they range from two to six millimeters across. The average diameter of the spots of yellow rain made available to us by the Canadian government is 3.2 millimeters, and the standard deviation of the distribution is one millimeter. The measurement is indistinguishable from the average diameters we measured for the fecal deposits of the two honeybee species we received from India.

Both honeybee feces and samples of yellow rain include high concentrations of pollen: approximately a million pollen grains per milligram. The pollen makes up about half of the volume of the material, and it is held in a coherent mass by an amorphous matrix that is only partially soluble in water. Bee hairs and bits of fungi are minor components both in samples of yellow rain and in bee feces.

We also tested the pollen grains in yellow rain for the presence of protein. It is known that when pollen passes through the digestive system of the bee, the contents of the pollen, including the protein, are digested out of it. On the other hand, pollen that does not pass through the bee retains its protein intact, and such pollen stains a deep blue in the presence of the dye Coomassie Brilliant Blue. We found that freshly gathered pollen, pollen taken from stores in the nests of bees and pollen from honey all stain deeply, which indicates a high protein content. In contrast, most of the pollen grains in bee feces are not stained by the dye. What is significant, the pollen found in our samples of yellow rain was not stained either, just as if it had been digested by bees. It would seem that in order to accept the chemical-warfare theory of yellow rain in the face of this evidence one would have to imagine an enemy so devious that its chemical weapon is prepared by gathering pollen predigested by honeybees.

The most detailed evidence for the origin of yellow rain is derived by analyzing scanning electron micrographs of the pollen it contains. Pollen grains carry the male genetic material for all plants that reproduce from seed. Almost all such grains have apertures, or thin, preformed areas in the grain wall, which allow the sperm nuclei to be released. The size of the grain, its surface sculpture and the shape and number of apertures on its surface can be highly specific for the taxon, or plant group, from which it comes. In combination such features can make it possible to distinguish pollen from different genera within the same plant family and, in some cases, to distinguish pollen from different species within the same genus. Since botanists recognize more than 200,000 species of flowering plants, pollen analysis can sometimes give specific information about the source of the materials that contain the pollen.

What happens to the distinctive appearance of the pollen grains when honeybees eat them? Typically the pollen is first gathered by older bees and stored in the nest. The young adult bees then eat it, whereupon most of the interior of the grain, including fats and protein, is digested by the bee. The exine, however, which is the outer shell of the grain, is indigestible and passes into the feces. The morphological characteristics relied on to identify pollen are largely unaffected by the bee's digestive system.

One of us (Nowicke), assisted by Janice Bittner, also of the Smithsonian Institution, has analyzed the pollen in the Canadian samples and in the ABC News sample of yellow rain. The work yields three important conclusions. First, all plant taxa that have been identified from the pollen in yellow rain are common in Southeast Asia, and their habitat is compatible with ecological conditions near the sites of the alleged chemical attacks. Second, many of the pollen types found in samples of yellow rain match the types found in honeybees, in honeybee feces collected in Thailand and in samples of honey collected in the mountains of northern Thailand and along the Thai-Laotian border. The presence of yellow rain pollen types in bees and bee feces validates the implication of our protein-stain experiment: the pollen was indeed gathered by Southeast Asian honeybees.

Third, no two spots of yellow rain that have been examined, not even adjacent spots on the same leaf, have the same mixture of pollen types. Instead there are wide variations from one spot to another. Such diversity in the composition of the pollen from spot to spot is characteristic of honeybee feces, but it would not be expected from a manmade mixture. Thus laboratory examination of the yellow rain samples, including the ABC News sample that reportedly contains trichothecene toxins, has provided detailed evidence that yellow rain is honeybee feces.

At this stage in our investigation it still remained an open question whether honeybee defecation could account for one of the central claims made by the refugees, namely that the alleged chemical-warfare agent falls in light showers like rain. We knew that honeybees do not normally defecate in their nests; instead they do so in flight. Indeed, beekeepers in temperate climates are familiar with the massive defecation flights of the European honeybee *Apis mellifera* on the first warm days of spring. The behavior is attributed to the bees' need to defecate after the long period of enforced confinement during cold winter weather. In the Tropics, however, such synchronized cleansing flights were not necessarily expected, and none had been reported in the scientific literature.

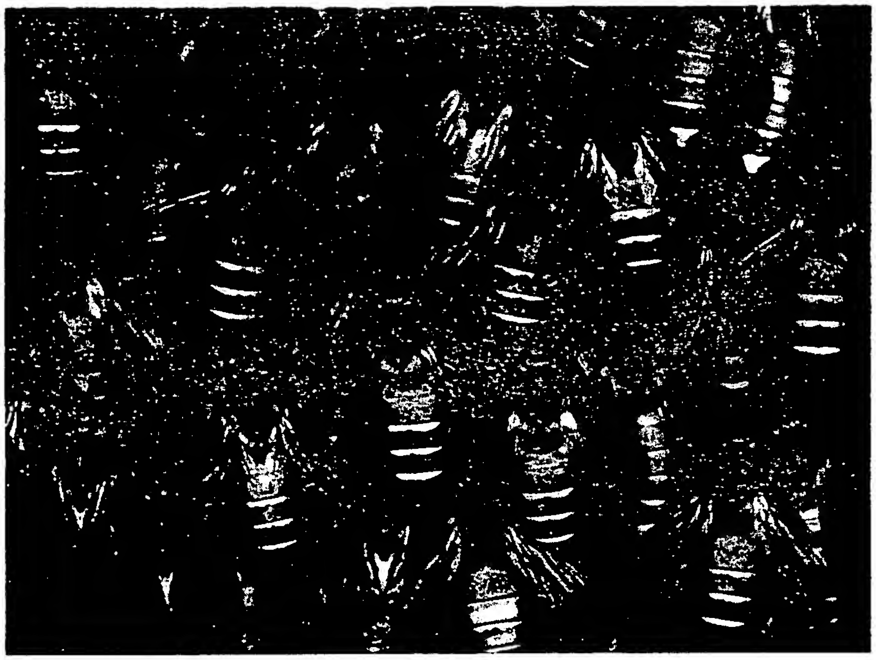
After proposing that yellow rain is the feces of Asian honeybees, we learned of a report published in China that described massive showers of bee feces in northern Jiangsu Province in September, 1976. The local population could not determine the cause of the phenomenon, and so it was brought to the attention of the geology department at Nanjing University. According to the report by Zhang Zhongying and his colleagues, the showers must have been extraordinary: they generally lasted for several minutes, and they deposited yellow spots rich in pollen over areas of from .2 hectare to six hectares. The spots ranged in diameter from two to six millimeters.

It is significant that no one who witnessed the showers reported seeing any bees overhead. The deposits were only later identified as honeybee feces through examination in the laboratory. The bee species was not identified, but the bees may not have been native: *A. mellifera* had been introduced into the region for the commercial production of honey some time before the cleansing flights were noticed. Nevertheless, the occurrence of massive cleansing flights in September showed that they need not take place only after a long period of cold weather.

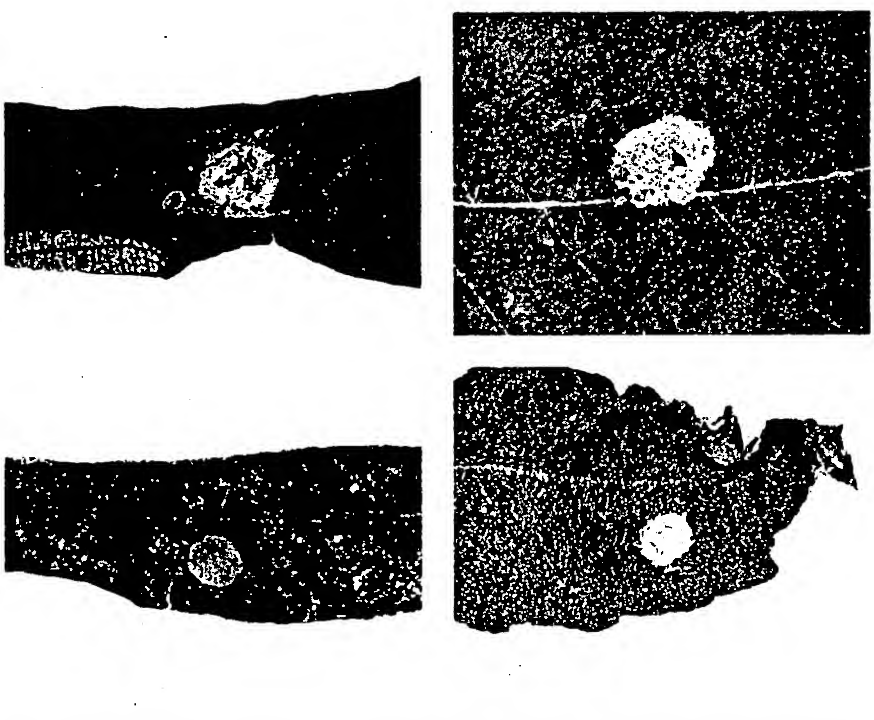
To determine whether honeybees indigenous to the Tropics of Southeast Asia also make such massive cleansing flights, three of us (Akratanakul, Meselson and Seeley) undertook a field study in Thailand in March, 1984. The bees we observed were mainly *A. dorsata*, one of the species of Asian honeybees and one of the two species whose fecal deposits we had already studied in the laboratory. The worker bees of *A. dorsata* are the largest workers among the Asian honeybees, and they usually build nests that hang from the limbs of tall trees in forests and villages. Typically the population of a nest is between 30,000 and 50,000 bees, and there is often more than one

nest in a single bee tree. Exceptional trees have as many as 100 nests.

We examined 10 nesting sites of *A. dorsata:* nine were in trees and one was under the eaves of a building. We found leaves, rocks or both spotted with honeybee feces at all the nesting sites. On horizontal surfaces the spots were circular; their average diameter was 3.2 ± .9 millimeters. The color of the spots on young leaves ranged from white through yellow to shades of brown and brownish red, although yellow was strongly predominant. The texture of the spots varied from waxy to powdery. At two nesting sites the air was particularly hot and dry, and there were no spots on the younger leaves of the vegetation. The absence of spots showed that the defecation flights had stopped at least several weeks earlier, even though at one site the bees were still foraging. We found recently fallen feces, including moist, sticky deposits, at all the other eight nesting sites.



***APIS DORSATA*, the giant Asian honeybee, is seen on the surface of a nest. Between 30,000 and 50,000 bees inhabit a typical nest, and often more than one nest is found in a tree.**



YELLOW RAIN and honeybee feces leave deposits that are indistinguishable to the eye. The spots on the leaves in the photographs at the left are the deposits made by yellow rain; the leaves were turned over to Canadian government officials in Thailand in April, 1982, by Hmong refugees. The refugees said they had collected the leaves at the site of a chemical attack in Laos the month before. The spots on the leaves in the photographs at the right are the fecal deposits of the Southeast Asian honeybees *Apis cerana* (*upper right*) and *A. dorsata* (*lower right*). The spots vary on the average from three to five millimeters in diameter.

We devoted our closest study to a site about 800 meters above sea level in the forest of Khao Yai National Park, where two of us (Akratanakul and Seeley) had investigated the behavior of honeybees in 1979 and 1980. The park includes 2,200 square kilometers of largely undisturbed evergreen forest in the mountains 120 kilometers northeast of Bangkok. The nesting site was a dead dipterocarp tree; hanging from a limb of the tree were three large nests of *A. dorsata* about 20 meters above the ground. A swath of yellow-spotted vegetation about 40 meters wide extended from near the base of the tree out to a distance of about 160 meters. The long axis of the swath followed a partial opening in the forest canopy, which ran downhill toward a valley about five kilometers away where the bees were probably foraging. Directly under the nests and out to about 20 meters from the tree the density of the spots in the swath was low, but it then increased sharply to a density of about 100 spots per square meter. The density remained at roughly this level out to about 120 meters from the tree before it finally began to decline. Our counts represented only two days' accumulation of spots because they were done following an unseasonably heavy rainstorm that had washed away most of the older deposits.

The mere observation of a fecal swath does not determine whether the deposition takes place as a distinct shower or as an intermittent spattering that occurs over a relatively long time. A shower would of course be compatible with the refugees' description of yellow rain. To resolve the question we placed six large sheets of white paper in various exposed places between 40 and 140 meters from the nesting site, near the center axis of the swath. We examined the sheets of paper periodically one morning between 7:00 A.M. and 12:30 P.M. Sometime between 9:00 and 9:35 A.M. there was a fecal shower. All six sheets registered the shower, and the average density of spots was 29 per square meter. If our samples were typical of the entire swath, the fecal shower must have covered at

least 6,000 square meters and deposited more than 100,000 spots.

We found that each spot on the sampling sheets included copious quantities of pollen. There were from 100,000 to a million pollen grains in a typical spot, just as there are in spots of yellow rain. We made scanning electron micrographs of the pollen in 10 of the spots and found there were different and sometimes widely varying mixtures of pollen in each spot. Two of the pollen types, which for convenience we call Elaeocarpus-like and Sterculia-like, match grains we had already seen in samples of yellow rain, including the ABC News sample. Indeed, most of the pollen types we identified in yellow rain are also found in samples of honey and feces of *A. dorsata* from Thailand.

During the shower recorded in Khao Yai National Park we were outside the swath, and so we could only conclude that the shower had lasted for no more than 35 minutes. Later we were actually caught in a fecal shower. We were visiting a region known for bee trees in which an unusually large number of nests are suspended. In the village of Khua Moong, about 20 kilometers south of Chiang Mai in Thailand, we examined the area around two such trees, one bearing about 30 nests and the other more than 80, hanging from 20 to 50 meters above the ground. As we observed the second tree through binoculars from a clearing about 150 meters away, we saw a lightening in the color of several nests. Hundreds of thousands of bees were suddenly leaving their nests. Moments later drops of bee feces began falling on and around the three members of our party. About a dozen spots fell on each of us. We could neither see nor hear the bees flying high above us.

The shower began at 5:17 P.M. and lasted for approximately five minutes. The density of the spots on the hood and roof of our parked Land Rover was 209 per square meter. The fresh deposits were sticky, and they varied in size and color much like the spots we collected at Khao Yai National Park. Our observations showed that showers of honeybee feces do indeed occur in the Tropics of Southeast Asia; moreover, the showers and spots closely resemble the showers and spots said to be caused by yellow rain.

We next sought to learn whether the Hmong refugees might mistake bee feces for an agent of chemical warfare. To investigate the question we went to the Ban Vinai refugee camp, where most of the interviews with witnesses of the alleged chemical attacks have been conducted. One of us (Akratanakul) speaks Lao and so we were able to question 16 groups of people we encountered at random in the camp.

We showed leaves spotted with the feces of *A. dorsata* to each group and asked them to identify the spots. Thirteen of the groups concluded they did not know what the spots were, although some people said they had seen such spots before. One group of nine people and one group of six told us the spots were *kemi*, their term for the alleged poison. The remaining group included three men, one of whom identified the spots as insect feces. No one else we encountered came as close as this man to a correct identification. After some discussion among themselves, however, the three men agreed the spots were *kemi*.

Our interviews with Hmong refugees from Laos indicate the Hmong do not generally recognize honeybee feces for what they are. Moreover, some of the Hmong identify bee feces as the alleged agent of chemical warfare.

We conclude that yellow rain is the feces of honeybees, not an agent of chemical warfare. This conclusion has emerged from many independent sources: from detailed laboratory comparisons of samples of yellow rain and bee feces, from field observations of the behavior of bees and from interviews with Hmong refugees. Bee fecal deposits account for all the consistently reported features of the deposits left by yellow rain, including their color, size and texture, their deposition in showers and their high pollen content. They also account for the results of our detailed pollen analysis and other laboratory tests.

A single clear discrepancy between yellow rain and bee feces, such as a mismatch between the average diameters of the two classes of spots, would naturally have forced us to reconsider our hypothesis. No such discrepancy has been found. In contrast, to support the hypothesis that yellow rain is a chemical-warfare agent one must invoke an entire series of unsupported suppositions. The chemical-warfare theory even fails to explain such striking properties of yellow rain as the presence and the variety of pollen in the samples.

It cannot be proved that some kind of chemical warfare has not taken place. The evidence for it, however, from interviews with alleged witnesses as well as from the chemical analysis of samples, is ambiguous and conflicting. We are reasonably confident about the origin of the alleged chemical agent itself, the yellow rain: it is a phenomenon of nature, not of man.

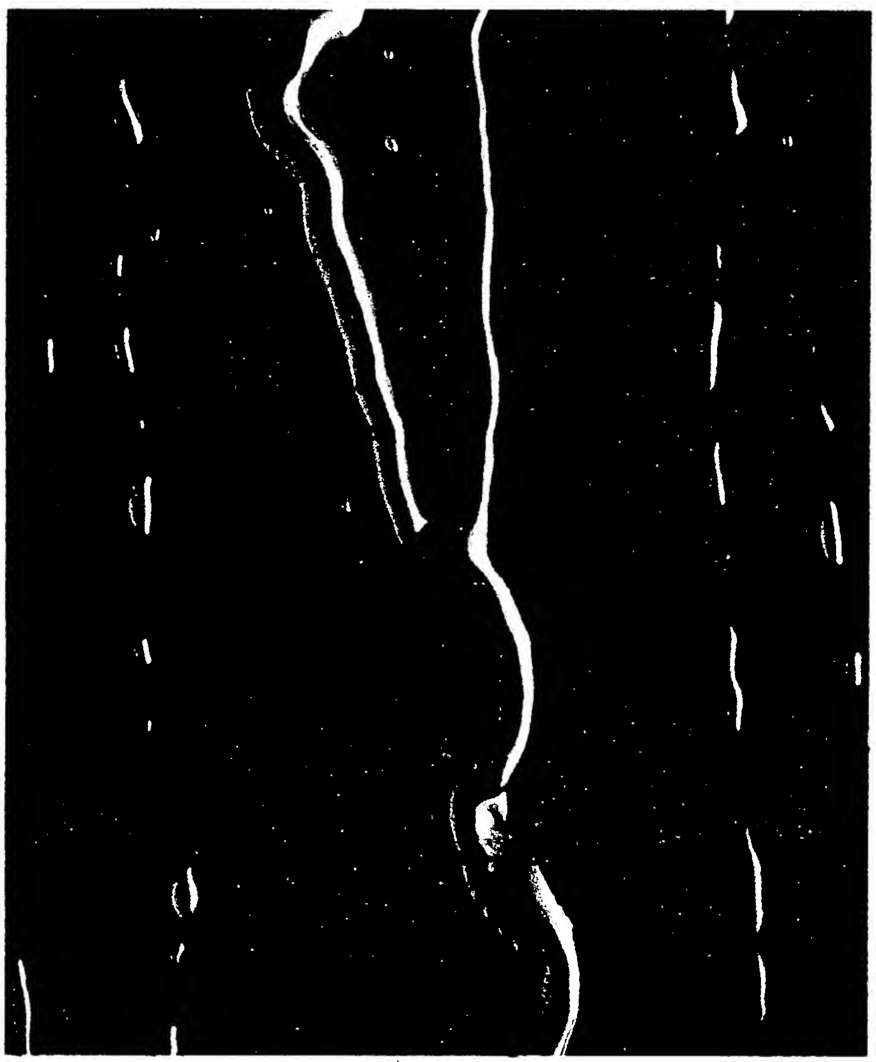
THE AMATEUR SCIENTIST

What forces shape the behavior of water as a drop meanders down a windowpane?

by Jearl Walker

A windowpane speckled with rain offers two subtle puzzles in the physics of fluids. How do the drops cling to the glass? When water runs down the glass in a stream, why does it often meander instead of going straight?

The clinging of drops is often attributed to the surface tension of water, yet under a common definition of surface tension the drops should not cling. Meandering is often attributed to contamination on the glass, yet contamination seems unlikely to account for the normally regular pattern of a meandering stream.



Drops of water and a meander on a sheet of Plexiglas

Imagine a small drop of water on a solid horizontal surface such as a piece of glass. If the drop does not spread over the surface as a film, it forms a roughly hemispherical, slightly flattened bead. The shape is determined in part by the mutual attraction of the water molecules; that force acts to minimize the surface area. The surface is effectively a stretched, elastic membrane.

Usually the tendency to minimize the surface area is described in terms of tension on the surface of the drop. Imagine a line running across that surface. The surface tension is represented by forces that pull perpendicularly to the line, causing it to be in a state of tension. The surface tension of the water is defined as the ratio of the force pulling on one side of the line to the length of the line.

The perimeter of the contact area between the drop and the solid surface is called the triple-phase line because of the conjunction of water, air and solid. The angle at which the water touches the solid at the triple-phase line is called the contact angle. It is measured between the solid and a tangent to the water surface. If the contact angle is less than 90 degrees, the water tends to spread over the solid and is said to wet it. If the angle is more than 90 degrees, the water pulls itself into a bead and does not wet the solid.

In the early part of the 19th century Thomas Young, who is remembered for his pioneering work on optical interference, stated that the size of the contact angle is set by the tendency toward equilibrium of three tensions pulling on the triple-phase line. The tension of solid and water pulls in one direction along the interface between the solid and the water in what is properly called an interfacial tension. The tension of solid and air pulls in the opposite direction. The surface tension of the water pulls along a tangent to the surface of the water.

The horizontal component of the pull from the water's surface tension is, say, rightward and its size depends on the cosine of the contact angle. According to Young's argument, if the triple-phase line is in equilibrium, so that the drop is neither spreading nor contracting, the net horizontal force on the line must vanish. A specific value of the contact angle results in a balance of the horizontal forces on the line.

Young's argument is simple, but no one has verified it experimentally. Moreover, measurements of the contact angle of water on a solid surface